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THE EFFECTS OF OBSTACLES ON SUNSHINE RECORDS

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THE EFFECTS OF OBSTACLES ON SUNSHINE RECORDS.

By E. G. Bilham, B.Sc., D.I.C.

Introductory.—It is well known that in selecting a position for a sunshine recorder the aim should be to choose a site where no obstacles can prevent registration at any time of the day or at any time of the year. It is also well known that a site fulfilling these conditions is very rarely procurable. Experience has shown that when the sun is less than 3 degrees above the horizon the intensity of the solar radiation is hardly ever sufficient to produce a record on the cards used in the standard Campbell-Stokes instrument. It is customary, therefore, to disregard obstacles subtending a vertical angle of no more than 3 degrees. In many places the proximity of hills, trees and buildings makes it difficult to find sites where even this modified condition is satisfied. Thus it comes about that sunshine recorders have been set up on many sites where obstacles prevent registration during certain periods. By making an accurate drawing, on an altitude-azimuth framework, of the horizon from north-east through south to north-west, and plotting on the same diagram position lines of the sun for different values of the solar declination it is possible to determine the periods during which registration is prevented ; the method is described in the " Meteorological Observer's Handbook " (1934 edition), pp. 95–6. We can then proceed to calculate the percentage cut-off of " recordable sunshine " for each calendar month and the year, the term " recordable sunshine " referring to the period when the sun's altitude is above 3°. In the *Monthly Weather Report*, and also in " Averages of Bright Sunshine ", a letter S is used to indicate that the cut-off calculated in this way exceeds 5 per cent.

It should be noted that this procedure takes no account of the actual incidence of sunshine ; it merely aims at determining how much record would be lost if the sun always shone brightly when its altitude exceeded 3°. The letter S appended to the data in the publications referred to above merely warns the reader that some record is lost owing to the presence of obstacles in the path of the sun's rays. So far as I can ascertain no attempt has hitherto been made to determine the actual extent to which average values are affected by an obstacle of given altitude. The purpose of this paper is to furnish information of that kind.

Obstacles may be of various types ; trees, hills and buildings are the most common. Trees introduce a complication, because if they are of deciduous species they may cut off sunshine completely when in full leaf, but scarcely at all when their branches are bare. Similarly, buildings may include chimneys from which dense smoke issues at times, and hills may give rise to orographic cloud which increases their effective altitude and azimuth as obstacles to sunshine. It is impossible, however, to take account of complications of this kind in the present investigation ; we shall deal simply with obstacles having a fixed profile and impenetrable to sunshine.

For the purpose of this investigation we require information in regard to the way in which the incidence of sunshine varies with the altitude of the sun at different times of the year. Assuming such

information to be available we can proceed to calculate how much sunshine is actually recorded on the average when the sun is below a given altitude, say $a°$, and we shall then know how much sunshine would be cut off if an obstacle subtending a vertical angle of $a°$, and suitably situated in azimuth, were present. This loss can be expressed as a percentage of the mean daily duration, thus providing a figure which can be compared directly with the calculated percentage loss of recordable sunshine. Since we do not possess data which give the mean duration for different solar altitudes, we have first to consider how such data can be derived from published averages of hourly values.

Method of Utilising Means of Hourly Values.—For the observatories at Kew, Valentia, Aberdeen and Falmouth we possess monthly means of hourly values of sunshine duration for the period 1881–1915*. The values refer to periods of 60 minutes centring at exact hours, local apparent time (L.A.T.) For a given month, say March, and for a given station, say Falmouth, we are thus in a position to determine the actual and percentage duration of sunshine recorded up to 6.30, 7.30, 8.30...a.m., or after...3.30, 4.30, 5.30 p.m. If we can ascertain the mean values of solar altitude corresponding to these times we have all the information required for the investigation.

Knowing the time, the sun's declination and the latitude of the place of observation, the sun's altitude can be calculated, or, alternatively, it can be read from tables such as Ball's Altitude Tables. The use of the tables is very tedious unless integral values of the declination and latitude are adopted. Since this paper does not aim at a very high degree of accuracy I have adopted the following approximate values of solar declination, which occur near the middle of the calendar months :

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
S.21°	S.13°	S.2°	N.10°	N.19°	N.23°	N.22°	N.14°	N.3°	S.9°	S.18°	S.23°

The latitudes of Aberdeen, Kew and Falmouth are very nearly 57°, 51½° and 50° respectively ; Valentia data were not used because that station has an obstructed horizon.

I have assumed that the means of hourly values are applicable to the midday of the month, or to be more precise, to the day on which the solar declination has the adopted integral value. This assumption is not strictly valid ; consider for example an equinoctial month such as March. At Falmouth the time of sunrise in an ordinary year varies from about 6.34 a.m. on March 1, to 5.38 a.m. on March 31. It is clear therefore that sunshine recorded before 6.30 a.m. must be contributed by days near the end of the month, when the solar declination is approaching the value of 4°N. The adopted mid-monthly value of solar declination for March is 2°S., and that is the value with which we enter the tables in order to convert time to solar altitude. By doing so we clearly make an

* *Hourly Values from Autographic Records*, 1915, 1916 and 1917. The values as published for Aberdeen are incorrect ; corrected values are given in the Appendix to this paper.

underestimate of the mean solar altitude corresponding to the average amount of sunshine recorded up to 6.30 a.m. Actually, the solar altitude corresponding to latitude 50°, declination 2°S. is 3·3°. This is a close approximation to the mean value of the solar altitude at 6.30 a.m. at Falmouth during the month of March, but it is an underestimate of the height of the obstacle necessary to cut off the mean daily amount of sunshine recorded at that station up to 6.30 a.m. It will be seen therefore that the method used tends to overestimate the amount of sunshine cut off by an obstacle of stated altitude. The error is clearly greatest in equinoctial months when the solar declination varies through a wide range.

The details of the method of procedure may be illustrated by reference to the results for Falmouth, for the month of March. From *Hourly Values from autographic records*, 1915, p. 28, we obtain the following 35-year means of the first few hourly values of sunshine duration :—

Hour (L.A.T.) ended at ..	6·30	7·30	8·30	9·30
Mean duration of sunshine (hrs.)	·01	·16	·37	·43

Mean daily total = 4·41 hrs.

By successive summation we obtain

Sunshine recorded up to 6.30 a.m.	= ·01 hr.	= 0·2	per cent of daily total.
,, ,, ,, 7.30 a.m.	= ·17 hr.	= 3·9	,, ,, ,,
,, ,, ,, 8.30 a.m.	= ·54 hr.	= 12·3	,, ,, ,,
,, ,, ,, 9.30 a.m.	= ·97 hr.	= 22·1	,, ,, ,,

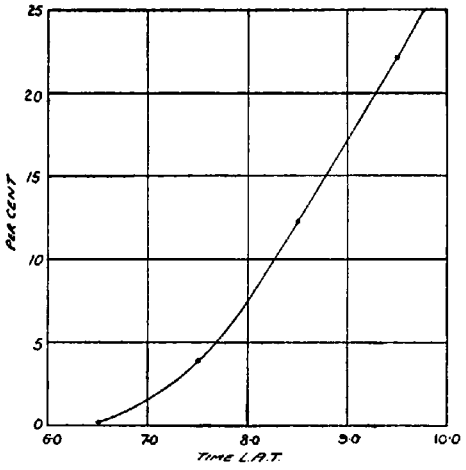

FIG. 1.—FALMOUTH, MARCH. AVERAGE PERCENTAGE OF DAY'S SUNSHINE RECORDED UP TO A GIVEN HOUR, LOCAL APPARENT TIME.

Plotting these percentages we obtain the curve shown in Fig. 1, from which we can readily read off the percentages recorded up to 7 a.m. (1·5) 8 a.m. (7·5) and 9 a.m. (17·3). Referring now to Ball's Altitude Tables we obtain the values of the sun's altitude at 6.30, 7.0, ... 9.0, 9.30 a.m. corresponding to declination 2° S, the mid-value for the month. We thus have the following data :—

Time, L.A.T. (T)	6.30	7.0	7.30	8.0	8.30	9.0	9.30
Sun's altitude ..	3·3°	8°	12·7°	17·1°	21·4°	25·3°	28·9°
Percentage of day's sunshine recorded up to time T ..	0·2	1·5	3·9	7·5	12·3	17·3	22·1

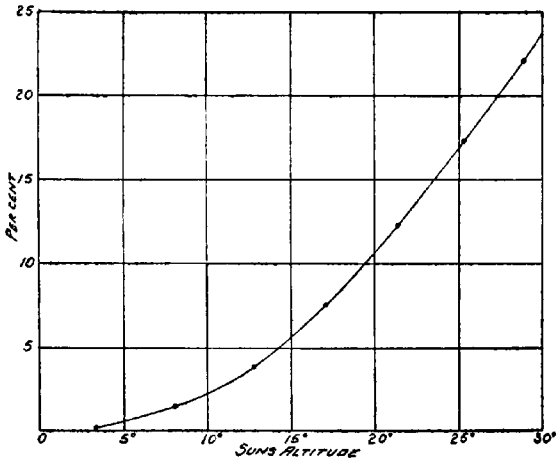

FIG. 2.—FALMOUTH, MARCH. AVERAGE PERCENTAGE OF DAY'S SUNSHINE RECORDED WHEN SUN'S ALTITUDE IS BELOW A GIVEN VALUE. (MORNING.)

By plotting the figures in the last line against the values of sun's altitude in the second line we obtain Fig. 2. From this curve we can read off the following percentages corresponding with selected values of the sun's altitude.

Percentage of day's sunshine recorded when sun's altitude in the morning is

below	6°	= 0·7	per cent
,,	8°	= 1·5	,, ,,
,,	10°	= 2·4	,, ,,
,,	12°	= 3·5	,, ,,

(Percentages corresponding to higher altitudes could of course have been read off, but this was not done.)

The actual amounts of sunshine in hours were then obtained by multiplying the percentages by the mean daily duration, 4·41 hours. Values of "percentage of possible" were also obtained by expressing the values of actual duration as percentages of the time taken by the sun to climb from the horizon to the stated altitude, on the midday of the month. To obtain values corresponding to the same solar altitudes in the afternoon the p.m. hourly values were used in a similar manner.

The data obtained in this way represent the losses that would arise from the presence of an obstacle of indefinite horizontal extent cutting off all sunshine from the horizon to the altitude considered. By taking differences we can estimate the loss due to an obstacle which comes into play while the sun's altitude is increasing or decreasing from one value to another. Thus, in the example given above, the average percentage loss in March due to an obstacle cutting off sunshine between altitudes 6° and 10° in the morning would be 2·4 – 0·7 or 1·7 per cent.

Results for Four Stations.—The method described above has been used to obtain the results set out in Table I. Data are given for the three observatories, Aberdeen (lat. 57°N), Kew (lat. 51½°N) and Falmouth (lat. 50°N).; together with Cranwell (lat. 53°N). For the three observatories the initial data were hourly means for the 35 years, 1881–1915, centred at exact hours (L.A.T). For Cranwell the hourly means (given in Appendix B) were computed for the period June, 1921 to March, 1935, and refer to intervals of 60 minutes ending at exact hours (L.A.T.). The procedure had therefore to be slightly modified in dealing with the data for this station. The following are brief particulars of the four stations :

Aberdeen.—Sunshine recorder 68 ft. above ground, 147 ft. above M.S.L.; excellent exposure on the roof of the observatory, King's College. A flagpole to the east, of angular diameter about 1°, may obstruct 0·1 hour sunshine about 7h. between April and September ; it has been the practice to make allowance for this obstruction whenever practicable, in tabulating the records. This station represents coastal conditions in an urban environment on the east coast of Scotland.

Cranwell.—Sunshine recorder 20 ft. above ground, 260 ft. above M.S.L. on office building on western edge of Royal Air Force Station ; unobstructed exposure ; surrounding country open and undulating. This station may be regarded as representing inland rural conditions.

Kew.—Sunshine recorder 44 ft. above ground, 62 ft. above M.S.L. The observatory is in a large open space, the Old Deer Park, Richmond, on the south-western outskirts of London. The recorder is on the Observatory roof and the sky-line is free from obstructions subtending an angle of more than 3° on the western horizon, or more than 1° on the eastern horizon.

Falmouth.—Sunshine recorder 34 ft. above ground, 201 ft. above M.S.L. on roof of observatory building in the middle of the town ; unobstructed exposure. This station represents coastal conditions in the extreme south of England.

At Aberdeen the noon altitude of the sun from about December 10 to January 3, is below 10° ; and from about November 26 to January 17 the noon altitude is below 12°. An obstacle subtending 10° in altitude and having sufficient extension in azimuth would cut off all sunshine between December 10 and January 3, and the loss due to such an obstacle in December would therefore approach 100 per cent ; an exact evaluation cannot however be made from the data available. For an obstacle of altitude 12° the loss is actually 100 per cent in December, a few days in November and part of January. The loss in January was regarded as indeterminate. These remarks explain the omissions in the Aberdeen data in Table I under headings 10° and 12°.

TABLE I—AVERAGE DAILY DURATION OF SUNSHINE WHEN SUN'S ALTITUDE IS BELOW STATED VALUE; IN ACTUAL HOURS (ORDINARY TYPE) AS PERCENTAGE OF DAILY TOTAL (ITALIC TYPE), AND AS PERCENTAGE OF POSSIBLE (DARK TYPE).

ABERDEEN.

Month.	Mean Daily Duration.	Morning.				Afternoon.				Total.			
		6°	8°	10°	12°	6°	8°	10°	12°	6°	8°	10°	12°
Jan. ..	1·47	·05	·10	·21	..	·10	·21	·37	..	·15	·31	·57	..
	..	*3·5*	*6·7*	*14·0*	..	*7·0*	*14·0*	*25·0*	..	*10·5*	*20·7*	*39·0*	..
	21	**4**	**6**	**10**	..	**8**	**13**	**17**	..	**6**	**9**	**13**	..
Feb. ..	2·51	·03	·07	·14	·23	·07	·12	·19	·29	·10	·18	·33	·52
	..	*1·0*	*2·6*	*5·5*	*9·0*	*2·8*	*4·7*	*7·7*	*11·5*	*3·8*	*7·3*	*13·2*	*20·5*
	28	**3**	**6**	**9**	**12**	**8**	**10**	**13**	**15**	**5**	**7**	**11**	**13**
Mar. ..	3·63	·04	·07	·11	·17	·05	·09	·14	·20	·09	·16	·25	·37
	..	*1·0*	*1·8*	*3·0*	*4·7*	*1·5*	*2·5*	*3·8*	*5·5*	*2·5*	*4·3*	*6·8*	*10·2*
	32	**5**	**7**	**9**	**11**	**6**	**9**	**11**	**13**	**6**	**8**	**10**	**12**
Apr. ..	5·09	·04	·07	·11	·17	·04	·07	·11	·17	·08	·14	·22	·34
	..	*0·8*	*1·4*	*2·2*	*3·3*	*0·7*	*1·4*	*2·2*	*3·4*	*1·5*	*2·8*	*4·4*	*6·7*
	37	**5**	**7**	**8**	**10**	**5**	**7**	**8**	**10**	**5**	**7**	**8**	**10**
May ..	5·86	·04	·08	·13	·19	·06	·11	·16	·23	·09	·18	·29	·42
	..	*0·6*	*1·3*	*2·2*	*3·3*	*1·0*	*1·8*	*2·7*	*3·9*	*1·6*	*3·1*	*4·9*	*7·2*
	37	**4**	**7**	**9**	**11**	**6**	**9**	**11**	**13**	**5**	**7**	**10**	**12**
June ..	5·95	·04	·08	·13	·20	·04	·08	·14	·21	·07	·16	·27	·41
	..	*0·6*	*1·3*	*2·2*	*3·2*	*0·6*	*1·4*	*2·3*	*3·6*	*1·2*	*2·7*	*4·5*	*6·8*
	35	**4**	**6**	**8**	**11**	**4**	**6**	**9**	**11**	**4**	**6**	**9**	**11**
July ..	4·97	·03	·06	·10	·16	·04	·07	·11	·16	·07	·13	·21	·32
	..	*0·5*	*1·2*	*2·0*	*3·2*	*0·8*	*1·4*	*2·2*	*3·3*	*1·3*	*2·6*	*4·2*	*6·5*
	30	**3**	**5**	**7**	**9**	**4**	**5**	**7**	**9**	**3**	**5**	**7**	**9**
Aug. ..	4·70	·03	·07	·10	·16	·04	·07	·10	·15	·07	·13	·21	·30
	..	*0·7*	*1·4*	*2·2*	*3·3*	*0·9*	*1·4*	*2·2*	*3·1*	*1·6*	*2·8*	*4·4*	*6·4*
	32	**3**	**6**	**8**	**10**	**5**	**6**	**8**	**9**	**4**	**6**	**8**	**9**
Sept. ..	4·00	·03	·06	·10	·16	·02	·06	·10	·13	·05	·12	·20	·28
	..	*0·8*	*1·5*	*2·6*	*3·9*	*0·5*	*1·4*	*2·5*	*3·2*	*1·3*	*2·9*	*5·1*	*7·1*
	32	**4**	**6**	**8**	**10**	**3**	**6**	**8**	**8**	**3**	**6**	**8**	**9**
Oct. ..	2·98	·05	·09	·14	·24	·06	·11	·17	·25	·11	·20	·31	·48
	..	*1·6*	*3·0*	*4·6*	*7·9*	*1·9*	*3·6*	*5·6*	*8·3*	*3·5*	*6·6*	*10·2*	*16·2*
	30	**6**	**8**	**10**	**14**	**7**	**10**	**12**	**14**	**6**	**9**	**11**	**14**
Nov. ..	1·74	·03	·08	·18	·30	·05	·11	·21	·34	·08	·19	·39	·64
	..	*1·7*	*4·7*	*10·5*	*17·5*	*2·9*	*6·2*	*11·8*	*19·5*	*4·6*	*10·9*	*22·3*	*37·0*
	23	**3**	**5**	**10**	**12**	**5**	**7**	**12**	**14**	**4**	**6**	**11**	**13**
Dec. ..	1·10	·07	·16	..	·52	·10	·22	..	·58	·17	·38	..	1·10
	..	*6·0*	*15·0*	..	*46·8*	*9·0*	*20·0*	..	*53·2*	*15·0*	*35·0*	..	*100*
	17	**6**	**8**	..	**15**	**9**	**11**	..	**17**	**8**	**10**	..	**16**
Year ..	3·67	·04	·08	..	..	·06	·11	..	..	·09	·19	..	..
	..	*1·1*	*2·2*	..	..	*1·5*	*3·0*	..	..	*2·6*	*5·2*	..	..
	31	**4**	**6**	..	..	**6**	**8**	..	..	**5**	**7**	..	

TABLE I—(*continued*)

CRANWELL

Month.	Mean Daily Duration.	Morning.				Afternoon.				Total.			
		6°	8°	10°	12°	6°	8°	10°	12°	6°	8°	10°	12°
Jan. ..	1·80	·05	·12	·21	·32	·02	·08	·16	·27	·07	·20	·37	·59
	..	*2·7*	*6·6*	*11·7*	*17·8*	*1·1*	*4·5*	*9·0*	*14·7*	*3·8*	*11·1*	*20·7*	*32·5*
	22	**5**	**9**	**13**	**15**	**2**	**6**	**10**	**13**	**4**	**8**	**11**	**14**
Feb. ..	2·41	·04	·09	·14	·20	·02	·05	·09	·14	·06	·14	·23	·34
	..	*1·8*	*3·6*	*5·7*	*8·3*	*0·8*	*2·1*	*3·9*	*6·0*	*2·6*	*5·7*	*9·6*	*14·3*
	25	**5**	**8**	**10**	**12**	**2**	**5**	**7**	**9**	**4**	**6**	**8**	**10**
Mar. ..	3·88	·02	·05	·08	·12	·02	·04	·08	·13	·04	·09	·16	·25
	..	*0·5*	*1·2*	*2·0*	*3·1*	*0·4*	*1·1*	*2·0*	*3·3*	*0·9*	*2·3*	*4·0*	*6·4*
	33	**3**	**5**	**7**	**8**	**3**	**4**	**7**	**9**	**3**	**5**	**7**	**9**
Apr. ..	4·52	·01	·04	·07	·12	·01	·04	·06	·10	·03	·08	·14	·22
	..	*0·3*	*0·9*	*1·6*	*2·6*	*0·3*	*0·8*	*1·4*	*2·2*	*0·6*	*1·7*	*3·0*	*4·8*
	33	**1**	**4**	**6**	**8**	**1**	**4**	**5**	**7**	**2**	**4**	**6**	**8**
May ..	5·82	·02	·06	·10	·16	·01	·05	·09	·15	·03	·11	·20	·31
	..	*0·4*	*1·0*	*1·8*	*2·8*	*0·2*	*0·8*	*1·6*	*2·5*	*0·6*	*1·8*	*3·4*	*5·3*
	39	**2**	**6**	**8**	**10**	**1**	**5**	**7**	**10**	**2**	**5**	**8**	**10**
June ..	6·62	·02	·05	·11	·17	·02	·07	·13	·21	·04	·12	·24	·38
	..	*0·3*	*0·8*	*1·6*	*2·5*	*0·3*	*1·0*	*2·0*	*3·2*	*0·6*	*1·8*	*3·6*	*5·7*
	39	**2**	**4**	**8**	**10**	**2**	**6**	**9**	**13**	**2**	**5**	**9**	**11**
July ..	6·48	·02	·06	·10	·17	·01	·04	·08	·14	·03	·10	·19	·31
	..	*0·3*	*0·9*	*1·6*	*2·6*	*0·2*	*0·6*	*1·3*	*2·2*	*0·5*	*1·5*	*2·9*	*4·8*
	40	**2**	**5**	**7**	**11**	**1**	**4**	**6**	**9**	**2**	**4**	**7**	**10**
Aug. ..	5·92	·03	·07	·11	·17	·02	·06	·10	·15	·05	·12	·21	·32
	..	*0·5*	*1·1*	*1·8*	*2·9*	*0·3*	*1·0*	*1·7*	*2·6*	*0·8*	*2·1*	*3·5*	*5·5*
	40	**4**	**7**	**9**	**12**	**3**	**6**	**8**	**10**	**3**	**7**	**9**	**11**
Sept. ..	4·78	·02	·04	·07	·12	·02	·06	·10	·15	·04	·11	·18	·28
	..	*0·4*	*0·9*	*1·5*	*2·5*	*0·5*	*1·3*	*2·1*	*3·2*	*0·9*	*2·2*	*3·6*	*5·7*
	38	**2**	**4**	**6**	**9**	**2**	**6**	**9**	**11**	**2**	**6**	**8**	**10**
Oct. ..	3·69	·03	·07	·13	·21	·03	·06	·11	·17	·06	·13	·24	·38
	..	*0·9*	*2·0*	*3·6*	*5·8*	*0·8*	*1·6*	*2·9*	*4·6*	*1·7*	*3·6*	*6·5*	*10·4*
	35	**4**	**7**	**10**	**14**	**4**	**6**	**9**	**11**	**4**	**6**	**9**	**12**
Nov. ..	2·20	·06	·10	·18	·28	·03	·07	·12	·21	·09	·17	·30	·49
	..	*2·6*	*4·8*	*8·0*	*12·8*	*1·4*	*3·0*	*5·5*	*9·7*	*4·0*	*7·8*	*13·5*	*22·5*
	29	**7**	**8**	**12**	**15**	**3**	**6**	**8**	**11**	**5**	**7**	**10**	**13**
Dec. ..	1·54	·05	·12	·24	·41	·03	·09	·18	·35	·08	·21	·42	·76
	..	*3·1*	*8·1*	*15·4*	*26·5*	*2·0*	*5·6*	*11·7*	*22·8*	*5·1*	*13·7*	*27·1*	*49·3*
	20	**5**	**8**	**13**	**17**	**3**	**6**	**9**	**14**	**4**	**7**	**11**	**15**
Year ..	4·14	·03	·07	·13	·20	·02	·06	·11	·18	·05	·13	·24	·38
	..	*0·7*	*1·7*	*3·1*	*4·8*	*0·5*	*1·4*	*2·7*	*4·3*	*1·2*	*3·1*	*5·8*	*9·1*
	34	**4**	**6**	**9**	**12**	**2**	**5**	**8**	**11**	**3**	**6**	**9**	**11**

TABLE I—(*continued*)

KEW

Month.	Mean Daily Duration.	Morning.				Afternoon.				Total.			
		6°	8°	10°	12°	6°	8°	10°	12°	6°	8°	10°	12°
Jan. ..	1·35	·00	·03	·07	·12	·03	·07	·12	·19	·03	·10	·19	·31
	..	*0·0*	*2·0*	*5·0*	*9·0*	*2·3*	*5·2*	*9·0*	*14·0*	*2·3*	*7·2*	*14·0*	*23·0*
	17	**0**	**2**	**4**	**6**	**3**	**6**	**7**	**10**	**2**	**4**	**6**	**8**
Feb. ..	2·10	·00	·01	·04	·08	·02	·04	·07	·12	·02	·06	·12	·19
	..	*0·0*	*0·7*	*1·9*	*3·6*	*1·0*	*2·0*	*3·5*	*5·6*	*1·0*	*2·7*	*5·6*	*9·2*
	22	**0**	**1**	**3**	**5**	**3**	**4**	**5**	**8**	**1**	**3**	**5**	**6**
Mar. ..	3·36	·00	·03	·05	·08	·03	·05	·08	·14	·03	·08	·13	·22
	..	*0·0*	*0·8*	*1·3*	*2·4*	*0·8*	*1·5*	*2·6*	*4·1*	*0·8*	*2·3*	*3·9*	*6·5*
	29	**0**	**3**	**4**	**6**	**4**	**5**	**7**	**10**	**2**	**4**	**6**	**8**
Apr. ..	5·18	·04	·07	·10	·14	·06	·10	·15	·19	·10	·17	·24	·34
	..	*0·8*	*1·3*	*1·9*	*2·8*	*1·2*	*1·9*	*2·8*	*3·7*	*2·0*	*3·2*	*4·7*	*6·5*
	38	**6**	**8**	**9**	**10**	**8**	**11**	**13**	**14**	**7**	**9**	**10**	**13**
May ..	6·46	·03	·06	·10	·16	·10	·16	·23	·29	·12	·22	·32	·45
	..	*0·4*	*0·9*	*1·5*	*2·4*	*1·5*	*2·5*	*3·5*	*4·5*	*1·9*	*3·4*	*5·0*	*6·9*
	42	**4**	**6**	**8**	**11**	**12**	**15**	**18**	**19**	**7**	**11**	**12**	**15**
June ..	6·53	·00	·03	·08	·13	·07	·14	·22	·29	·07	·17	·30	·42
	..	*0·0*	*0·5*	*1·2*	*2·0*	*1·0*	*2·2*	*3·3*	*4·4*	*1·0*	*2·7*	*4·5*	*6·4*
	40	**0**	**3**	**6**	**8**	**8**	**13**	**16**	**18**	**4**	**8**	**11**	**13**
July ..	6·50	·00	·03	·08	·14	·07	·14	·23	·30	·07	·18	·31	·44
	..	*0·0*	*0·5*	*1·2*	*2·1*	*1·0*	*2·2*	*3·5*	*4·6*	*1·0*	*2·7*	*4·7*	*6·7*
	40	**0**	**3**	**6**	**9**	**8**	**13**	**17**	**19**	**4**	**8**	**11**	**14**
Aug. ..	6·03	·02	·05	·09	·14	·07	·13	·20	·27	·09	·18	·29	·41
	..	*0·3*	*0·8*	*1·5*	*2·3*	*1·2*	*2·2*	*3·3*	*4·5*	*1·5*	*3·0*	*4·8*	*6·8*
	41	**3**	**5**	**7**	**10**	**9**	**14**	**16**	**19**	**6**	**9**	**12**	**15**
Sept.	4·84	·01	·03	·05	·09	·04	·08	·14	·19	·06	·11	·19	·28
	..	*0·3*	*0·6*	*1·1*	*1·9*	*0·9*	*1·6*	*2·8*	*4·0*	*1·2*	*2·2*	*3·9*	*5·9*
	38	**1**	**3**	**5**	**6**	**6**	**9**	**13**	**13**	**4**	**6**	**9**	**10**
Oct.	2·94	·01	·04	·08	·12	·02	·07	·11	·16	·03	·11	·19	·28
	..	*0·2*	*1·4*	*2·7*	*4·1*	*0·8*	*2·3*	*3·9*	*5·6*	*1·0*	*3·7*	*6·6*	*9·7*
	28	**1**	**4**	**7**	**8**	**3**	**7**	**9**	**11**	**2**	**6**	**8**	**10**
Nov. ..	1·73	·00	·04	·06	·10	·02	·08	·15	·21	·02	·13	·21	·31
	..	*0·1*	*2·4*	*3·5*	*5·6*	*1·3*	*4·9*	*8·5*	*12·4*	*1·4*	*7·3*	*12·0*	*18·0*
	20	**0**	**3**	**4**	**6**	**2**	**7**	**10**	**12**	**1**	**6**	**7**	**9**
Dec. ..	1·17	·00	·04	·09	·18	·02	·08	·14	·23	·02	·12	·23	·41
	..	*0·0*	*3·3*	*8·0*	*15·3*	*2·0*	*6·5*	*12·0*	*19·4*	*2·0*	*9·8*	*20·0*	*34·7*
	17	**0**	**3**	**5**	**8**	**2**	**6**	**8**	**11**	**1**	**5**	**7**	**9**
Year ..	3·96	·01	·04	·07	·12	·05	·09	·15	·21	·06	·13	·22	·33
	..	*0·3*	*1·0*	*1·8*	*3·0*	*1·2*	*2·4*	*3·8*	*5·4*	*1·5*	*3·4*	*5·6*	*8·4*
	33	**1**	**4**	**5**	**8**	**6**	**9**	**11**	**13**	**4**	**6**	**8**	**10**

TABLE I—(*continued*)

FALMOUTH

Month.	Mean Daily Duration.	Morning.				Afternoon.				Total.			
		6°	8°	10°	12°	6°	8°	10°	12°	6°	8°	10°	12°
Jan. ..	1·82	·04	·09	·14	·21	·03	·07	·13	·21	·07	·16	·27	·42
	..	*2·1*	*4·7*	*7·7*	*11·8*	*1·8*	*3·9*	*7·0*	*11·2*	*3·9*	*8·6*	*14·7*	*23·0*
	22	**5**	**8**	**10**	**12**	**4**	**6**	**9**	**12**	**4**	**7**	**9**	**12**
Feb. ..	2·94	·04	·08	·13	·18	·04	·08	·12	·18	·08	·16	·25	·35
	..	*1·4*	*2·7*	*4·4*	*6·0*	*1·3*	*2·6*	*4·2*	*6·0*	*2·7*	*5·3*	*8·6*	*12·0*
	30	**5**	**8**	**11**	**12**	**5**	**8**	**10**	**12**	**5**	**8**	**10**	**12**
Mar. ..	4·40	·04	·07	·11	·15	·05	·09	·14	·20	·08	·15	·24	·35
	..	*0·8*	*1·5*	*2·4*	*3·5*	*1·1*	*2·0*	*3·1*	*4·5*	*1·9*	*3·5*	*5·5*	*8·0*
	38	**6**	**8**	**10**	**11**	**7**	**10**	**13**	**15**	**6**	**9**	**11**	**13**
Apr. ..	6·07	·04	·07	·12	·17	·12	·16	·21	·27	·16	·23	·33	·44
	..	*0·7*	*1·2*	*2·0*	*2·8*	*1·9*	*2·6*	*3·5*	*4·5*	*2·6*	*3·8*	*5·5*	*7·3*
	45	**6**	**8**	**11**	**13**	**16**	**18**	**19**	**21**	**11**	**13**	**15**	**17**
May ..	7·36	·03	·07	·14	·21	·06	·11	·18	·26	·09	·18	·32	·46
	..	*0·4*	*1·0*	*1·9*	*2·8*	*0·8*	*1·5*	*2·4*	*3·5*	*1·2*	*2·5*	*4·3*	*6·3*
	48	**4**	**7**	**12**	**15**	**8**	**11**	**15**	**18**	**6**	**9**	**13**	**16**
June ..	7·28	·04	·09	·15	·22	·04	·09	·17	·25	·08	·18	·32	·47
	..	*0·5*	*1·2*	*2·0*	*3·0*	*0·6*	*1·3*	*2·4*	*3·5*	*1·1*	*2·5*	*4·4*	*6·5*
	45	**5**	**9**	**12**	**15**	**5**	**9**	**14**	**17**	**5**	**9**	**13**	**16**
July ..	7·19	·03	·06	·12	·18	·04	·09	·17	·25	·07	·15	·28	·43
	..	*0·4*	*0·9*	*1·6*	*2·5*	*0·5*	*1·2*	*2·3*	*3·5*	*0·9*	*2·1*	*3·9*	*6·0*
	46	**4**	**6**	**10**	**12**	**5**	**9**	**13**	**17**	**4**	**7**	**11**	**15**
Aug. ..	6·89	·04	·08	·14	·19	·05	·10	·17	·25	·10	·19	·31	·45
	..	*0·6*	*1·2*	*2·0*	*2·8*	*0·8*	*1·5*	*2·5*	*3·7*	*1·4*	*2·7*	*4·5*	*6·5*
	47	**6**	**9**	**12**	**14**	**7**	**11**	**15**	**18**	**7**	**10**	**13**	**16**
Sept. ..	5·41	·04	·08	·12	·17	·05	·09	·15	·22	·09	·17	·27	·39
	..	*0·8*	*1·4*	*2·2*	*3·2*	*0·9*	*1·7*	*2·7*	*4·1*	*1·7*	*3·1*	*4·9*	*7·3*
	43	**6**	**9**	**11**	**13**	**8**	**10**	**14**	**17**	**7**	**10**	**12**	**15**
Oct. ..	3·68	·03	·07	·13	·19	·05	·09	·14	·22	·08	·16	·27	·40
	..	*0·9*	*1·9*	*3·4*	*5·2*	*1·3*	*2·5*	*3·9*	*5·6*	*2·2*	*4·4*	*7·3*	*10·8*
	35	**4**	**8**	**11**	**13**	**7**	**10**	**12**	**16**	**6**	**9**	**12**	**14**
Nov. ..	2·48	·02	·07	·15	·23	·03	·07	·13	·21	·05	·15	·28	·44
	..	*0·9*	*3·0*	*6·0*	*9·4*	*1·2*	*3·0*	*5·4*	*8·4*	*2·1*	*6·0*	*11·4*	*17·8*
	28	**3**	**6**	**11**	**14**	**4**	**6**	**10**	**13**	**3**	**7**	**10**	**13**
Dec. ..	1·73	·05	·10	·17	·26	·04	·09	·16	·24	·09	·19	·33	·50
	..	*2·6*	*5·7*	*10·0*	*15·0*	*2·3*	*5·0*	*9·0*	*14·0*	*4·9*	*10·7*	*19·0*	*29·0*
	22	**5**	**8**	**11**	**13**	**4**	**7**	**10**	**12**	**5**	**8**	**11**	**13**
Year ..	4·77	·04	·08	·13	·20	·05	·09	·16	·23	·09	·17	·29	·43
	..	*0·8*	*1·6*	*2·8*	*4·1*	*1·0*	*1·9*	*3·3*	*4·8*	*1·8*	*3·5*	*6·1*	*8·9*
	39	**5**	**8**	**10**	**13**	**7**	**9**	**13**	**15**	**6**	**8**	**12**	**14**

The values under the heading "Total" in Table I were obtained by adding together the "morning" and "afternoon" values. From the point of view of determining losses due to obstacles these combined results are perhaps of less interest than those in the preceding columns, because it is uncommon in practice to find similar obstacles on both eastern and western horizons. On the other hand, the irregularities present in the results for morning and afternoon tend to be smoothed out in the combined values, and for that reason the latter have been selected for illustration in Fig. 3 and Fig. 4. It should be noted that in these figures the year is regarded as running from June 1 to May 31.

Discussion of Results.—Perhaps the most striking fact brought out by Fig. 3 is the remarkable uniformity in the percentage values during the summer half-year. From March to September there is little variation either from month to month or from place to place. The means for the seven months at the four stations are as follows.:—

	6°	8°	10°	12°
	%	%	%	%
Aberdeen	1·6	2·9	4·9	7·3
Cranwell	0·7	1·9	3·4	5·5
Kew	1·3	2·6	4·5	6·5
Falmouth	1·5	2·9	4·7	6·8
Mean ..	1·3	2·6	4·4	6·5

It appears that we should make little error if we took the mean values in the last line of this table as applicable to any place in Great Britain in any month of the summer half-year.

During the remainder of the year we have an entirely different state of affairs ; the percentage values rise to a sharp maximum in December. In general the height of the maximum peak increases with the north latitude of the station, though we may notice that at Falmouth the December values for 6° and 8° are higher than at Kew. At Kew indeed the winter maximum is practically non-existent in the 6° curve.

Turning to Fig. 4, we see that the values expressed in actual hours show a different form of annual variation and that there are marked differences from station to station. At Aberdeen and Cranwell there is a well-defined winter maximum in all four curves. Both stations also show a secondary maximum in the summer, with equinoctial minima. At Kew the 8°, 10° and 12° curves show a major maximum in the summer, a slightly less conspicuous maximum in the winter, and well-marked equinoctial minima ; the 6° curve shows a summer maximum and winter minimum. At Falmouth, the annual variation is relatively small, with no more than a tendency towards solsticial maxima and equinoctial minima.

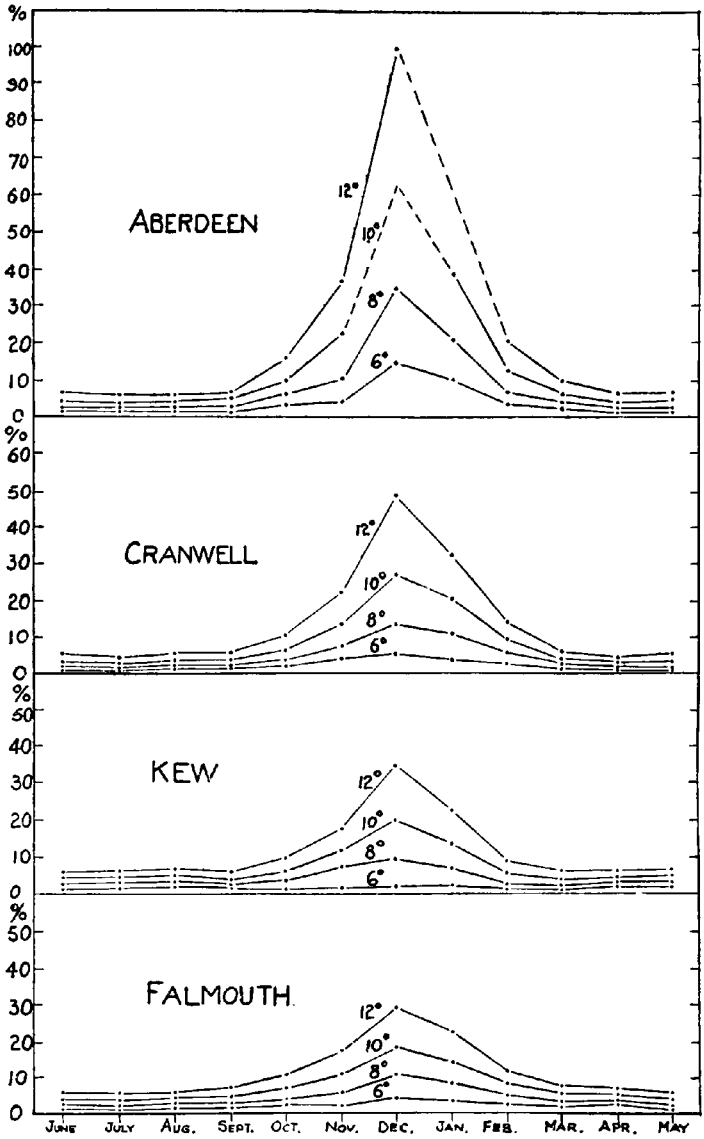

FIG. 3.—PERCENTAGE DURATION OF SUNSHINE WHEN SUN IS BELOW STATED ALTITUDE.

It is interesting to compare the curves in Fig. 3 and Fig. 4, which relate to actual records of sunshine, with those in Fig. 5, which refer to " possible " sunshine with sun's altitude 0° to 8°. In Fig. 5 curves are shown for latitudes 50° (Falmouth) and 57° (Aberdeen) ; (A), shows actual duration in hours (cf. Fig. 4) and (B) shows the duration expressed as a percentage of the length of the day (cf. Fig. 3).

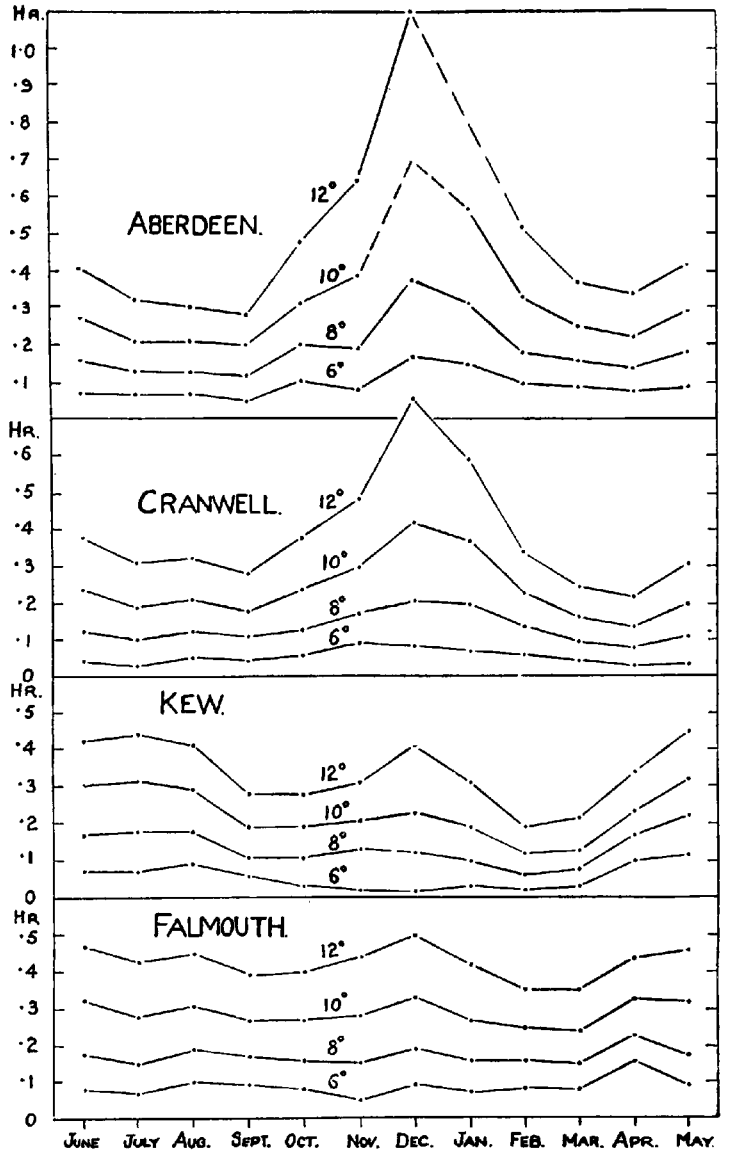

FIG. 4.—AVERAGE DAILY DURATION OF SUNSHINE WHEN SUN IS BELOW STATED ALTITUDE.

It will be seen that there is a very considerable degree of resemblance between the " recorded " curves of Figs. 3 or 4 and the " possible " curves of Fig. 5. In particular we may note in Fig. 5(B) the flatness of the percentage curves from March to September, and the small variation with latitude of the percentage during these months.

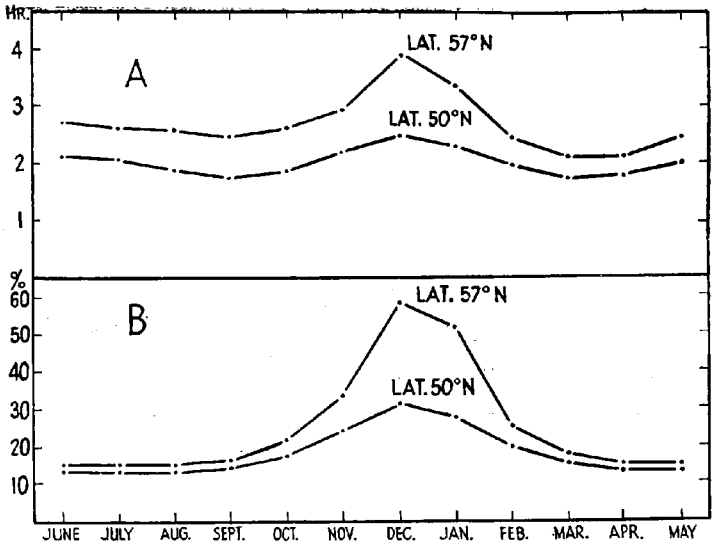

FIG. 5.—(A) MEAN DAILY DURATION OF PERIOD WHEN SUN'S ALTITUDE IS 8° OR LESS. (B) SAME VALUES EXPRESSED AS PERCENTAGES OF MEAN INTERVAL BETWEEN SUNRISE AND SUNSET (MID-MONTHLY VALUES).

Table II gives a comparison between the actual and calculated percentages of cut-off of recordable sunshine due to an obstacle subtending an angle of 8° on both horizons. The actual values are those taken from Table I, rounded off; the calculated values were obtained by expressing the time occupied by the sun in rising from altitude 3° to altitude 8°, multiplied by 2, as a percentage of the theoretical daily duration of recordable sunshine. The calculated percentage represents the loss that would occur if the incidence of sunshine were independent of the sun's altitude. We see that in general the actual loss is very substantially less than the calculated loss, though in December at Aberdeen the two values tend to coincide. The letter S is used in the *Monthly Weather Report* to denote a calculated loss exceeding 5 per cent, but we may judge from Table II that when the calculated loss is in the neighbourhood of 5 per cent the actual loss is insignificant and negligible for practical purposes, so long as we are considering obstacles which merely cut off " horizon " sunshine.

It is necessary, however, to emphasise the fact that all these conclusions refer to monthly averages. On individual days, the actual loss will frequently approximate to the calculated loss and may represent a large percentage of the total for the day. Although, therefore, this investigation leads to the general conclusion that obstacles of the kind usually found at climatological stations do not seriously affect the published average values, it is nevertheless important that the horizon should be as free as possible from obstructions.

TABLE II.—COMPARISON OF ACTUAL AND CALCULATED PERCENTAGES OF CUT-OFF OF RECORDABLE SUNSHINE DUE TO AN OBSTACLE SUBTENDING AN ANGLE OF 8° ON BOTH HORIZONS.

Month.	Aberdeen.		Cranwell.		Kew.		Falmouth.	
	Actual.	Calculated.	Actual.	Calculated.	Actual.	Calculated.	Actual.	Calculated.
	%	%	%	%	%	%	%	%
January ..	21	30	11	20	7	19	9	17
February ..	7	15	6	13	3	13	5	12
March	4	11	2	9	2	9	4	9
April	3	9	2	8	3	8	4	7
May	3	8	2	8	3	8	3	7
June	3	8	2	8	3	8	3	7
July	3	8	2	8	3	8	2	7
August	3	8	2	8	3	8	3	7
September ..	3	9	2	9	2	8	3	8
October ..	7	13	4	12	4	12	4	10
November ..	11	19	8	17	7	15	6	15
December ..	35	39	14	24	10	21	11	19
Year	5·2	13·9	3·1	11·6	3·4	10·9	3·5	10·5

The calculated losses in minutes due to an obstacle of stated altitude on either horizon at Aberdeen, Cranwell, Kew and Falmouth are shown in Table III. These are mid-monthly values and are equivalent to the maximum losses occurring about the middle of the month on a day of uninterrupted sunshine, assuming that recording begins (in the absence of obstacles) when the sun's altitude is 3° above the eastern horizon and terminates when the sun is 3° above the western horizon.

TABLE III—CALCULATED LOSS OF RECORDABLE SUNSHINE DUE TO AN OBSTACLE OF STATED ALTITUDE ON EITHER HORIZON. (MID-MONTHLY VALUES IN MINUTES.)

Month.	Aberdeen.				Cranwell.				Kew.				Falmouth.			
	6°	8°	10°	12°	6°	8°	10°	12°	6°	8°	10°	12°	6°	8°	10°	12°
January	35	64	101	185	29	49	73	100	26	46	66	88	24	43	62	81
February	26	45	65	87	24	39	56	73	22	37	53	70	21	36	51	66
March	22	38	53	68	20	33	47	61	19	32	45	59	18	31	44	58
April	22	37	52	67	20	33	46	60	20	32	45	58	19	31	44	56
May	26	42	57	72	23	37	51	65	22	35	49	63	20	34	47	61
June	27	45	61	78	24	39	54	69	23	37	51	66	22	36	50	63
July	27	44	60	75	24	39	54	68	23	37	51	65	21	35	49	62
August	24	39	54	69	21	35	48	61	20	33	47	60	19	32	45	58
September	22	37	52	67	20	33	47	60	19	31	44	58	18	31	44	56
October	25	42	59	77	22	36	51	67	21	35	50	65	20	33	48	62
November	31	55	81	115	27	44	63	86	23	42	60	78	23	40	57	74
December	41	78	166	162	31	54	81	116	28	49	73	100	26	46	67	90

Referring back to Table I it is of interest to note that the afternoon values are in general higher than the morning values except at Cranwell; the difference is particularly marked at Kew. This asymetry in the daily variation of sunshine would appear to be a consequence of the fact that turbulence, which tends to disperse fog and smoke, reaches its maximum value two or three hours after noon. Conditions in which the atmospheric obscurity is sufficient to prevent the registration of sunshine will thus tend to occur more often in the hour or two following sunrise than in the hour or two before sunset. At Kew, hardly any sunshine is recorded until the sun has risen above altitude 6° in the morning and the average duration at all stages up to altitude 12° is very small compared with either Cranwell or Falmouth. On the other hand, the afternoon values for Kew closely resemble those for Falmouth and are distinctly higher than those for Cranwell. There can be little doubt that the marked deficiency of early morning sunshine at Kew is due to the fact that a vast smoke-producing area lies to the eastward of the observatory. To westward, the district is of a suburban residential character producing little smoke in summer months. At Cranwell, the only important local source of atmospheric pollution, namely the Royal Air Force Station, lies to westward of the recorder, and it seems clear that this circumstance must account for the relative deficiency of late afternoon sunshine.

In general the values for altitude 8° are about double those for altitude 6° indicating that an obstacle cutting off sunshine from altitude 6° to 8° is about equivalent, on the average, to one which cuts off all sunshine up to altitude 6°. Above 8°, the effect of an increment of 2° becomes increasingly serious, particularly when we consider the winter values for the more northerly stations. Thus a chimney rising to altitude 12° might easily double or treble the cut-off due to a building the main body of which extends only to altitude 6° or 7°.

Finally, we may consider the bearing of the results of this investigation on a proposal that has been put forward on various occasions. The proposal is that percentage of possible sunshine should be computed in respect to sunshine which it is actually possible to record at the station, not to the astronomically possible sunshine. It has been urged, and with some show of reason, that if a station is, for example, in a valley surrounded by hills, the cut-off due to the obstructions should be taken into account when computing the percentage of possible sunshine actually recorded. For the purpose of discussing the merits of this proposal, let us consider as an example what would happen if the recorder at Kew were prevented by obstacles from recording all sunshine when the sun's altitude was below 10°. From the data of Table I, we see that the mean daily sunshine for the whole year would be reduced from 3·96 hours to 3·96 − 0·22 or 3·74 hours. The mean daily cut-off of possible sunshine would be 2·63 hours per day and the mean daily duration

of possible sunshine would be reduced from 12·21 to 12·21–2·63 or 9·58 hours. The percentage of possible sunshine would thus become

$$\frac{3{\cdot}74}{9{\cdot}58} \times 100, \text{ or } 39 \text{ per cent}$$

as compared with the existing value of

$$\frac{3{\cdot}96}{12{\cdot}21} \times 100, \text{ or } 33 \text{ per cent.}$$

The presence of the obstruction would thus substantially increase the apparent value of the " percentage of possible." By ignoring the obstructions, as is the present practice, we should arrive at a value of

$$\frac{3{\cdot}74}{12{\cdot}21} \times 100, \text{ or } 31 \text{ per cent.}$$

It is clear, therefore, that although a slight underestimate of the true " percentage of possible " is made by ignoring the obstructions, a much more serious over-estimate would be made if the proposed method of computation were adopted. The proposed method really assumes that the recorded amount of sunshine is spread uniformly over the day, and that assumption is, as we have seen, invalid.

APPENDIX

A.—Corrected hourly averages (1881-1915) of duration of sunshine at Aberdeen. Local Apparent Time.

Hour ending	4.30	5.30	6.30	7.30	8.30	9.30	10.30	11.30	12.30	13.30	14.30	15.30	16.30	17.30	18.30	19.30	20.30	Day.
	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.
January	..	..	..	..	·00	·05	·21	·29	·30	·29	·24	·08	·02	..	..	..	..	1·47
February ..	..	..	..	..	·06	·24	·34	·38	·38	·38	·35	·27	·10	·01	..	..	..	2·51
March	..	..	·01	·11	·29	·38	·42	·43	·42	·40	·39	·35	·29	·14	·01	..	..	3·63
April	..	·02	·16	·30	·40	·45	·46	·47	·48	·48	·46	·45	·42	·35	·17	·02	..	5·09
May	·01	·18	·32	·37	·41	·44	·44	·45	·47	·46	·47	·46	·44	·39	·34	·20	·03	5·86
June	·07	·23	·31	·35	·38	·41	·43	·45	·45	·45	·46	·44	·41	·39	·36	·27	·08	5·95
July	·04	·19	·26	·33	·35	·37	·37	·37	·39	·38	·37	·37	·35	·32	·28	·20	·05	4·97
August	·00	·06	·21	·30	·36	·39	·40	·42	·43	·43	·42	·39	·36	·29	·19	·06	·00	4·70
September ..	..	..	·04	·20	·33	·39	·42	·41	·42	·41	·40	·38	·34	·23	·03	..	..	4·00
October	..	..	..	·02	·16	·32	·38	·39	·39	·40	·38	·32	·19	·03	..	..	..	2·98
November ..	..	..	..	..	·00	·11	·26	·30	·32	·32	·27	·13	·01	..	..	..	..	1·74
December ..	..	..	..	..	..	·01	·14	·24	·27	·25	·17	·03	·00	..	..	..	..	1·10
Year ..	·01	·06	·11	·17	·23	·30	·36	·38	·39	·39	·37	·31	·24	·18	·11	·06	·01	3·67

APPENDIX—*continued.*

B.—HOURLY AVERAGES (JUNE 1921—MARCH 1935) OF DURATION OF SUNSHINE AT CRANWELL, LINCOLNSHIRE. LOCAL APPARENT TIME.

Hour ending.	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	Day.
	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.
January	..	..	..	..	·06	·23	·30	·34	·33	·30	·21	·03	..	..	..	..	1·80
February	..	..	·00	·05	·21	·31	·35	·35	·35	·32	·27	·17	·03	..	..	..	2·41
March	..	..	·04	·22	·36	·42	·46	·47	·46	·45	·41	·34	·22	·03	..	..	3·88
April	..	·04	·22	·35	·42	·45	·44	·46	·45	·43	·42	·35	·28	·18	·03	..	4·52
May	·03	·24	·37	·42	·46	·49	·48	·51	·48	·46	·45	·45	·40	·34	·22	·02	5·82
June	·09	·29	·41	·45	·48	·50	·50	·52	·53	·52	·52	·47	·45	·42	·35	·12	6·62
July	·08	·29	·41	·47	·49	·51	·51	·54	·51	·50	·50	·48	·44	·40	·30	·05	6·48
August	·00	·14	·36	·45	·51	·52	·53	·50	·51	·52	·51	·48	·42	·34	·13	·00	5·92
September	..	·00	·10	·33	·45	·51	·52	·51	·52	·49	·46	·42	·33	·13	·01	..	4·78
October	..	..	·00	·13	·36	·46	·50	·49	·48	·45	·40	·32	·10	·00	..	..	3·70
November	..	..	..	·01	·13	·29	·35	·37	·37	·33	·27	·09	..	..	..	..	2·21
December	..	..	..	..	·02	·19	·28	·31	·31	·27	·15	·01	..	..	..	..	1·54
Year	·02	·09	·16	·24	·33	·41	·43	·45	·44	·42	·38	·30	·22	·15	·09	·02	4·15

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